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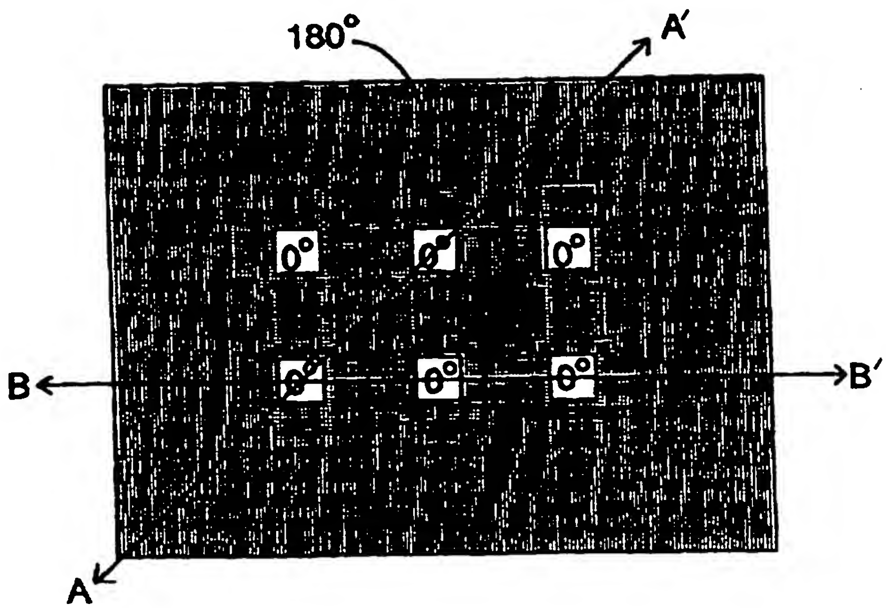
(54) Title: SIDELOBE SUPPRESSING ATTENUATED PHASE-SHIFTING MASK



(57) Abstract

A phase shift mask of the attenuating type for dense array image formation and large feature formation without printing sidelobes. For dense arrays, each zero phase E-field transmitting region (103) is surrounded by a 180 degree phase transmitting region (104) and an opaque non-transmitting region (105) is centrally located between each adjacent four zero phase regions. For large features, opaque material borders each corner and along long lines.

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SIDELOBE SUPPRESSING ATTENUATED PHASE-SHIFTING MASK

Field of the Invention

This invention relates to the structure of a mask for optical lithography. More particularly, it relates to a phase shift mask of the attenuating type. This type of phase shift mask finds particular application in lithography involving tiny features in arrays of dense patterns.

Background

Optical lithography has advanced in recent years in its ability to produce tiny features. The most important recent advance in lithography was the introduction of a photomask structure called a phase shift mask. Phase shift masks enable compensation for the diffraction effects which otherwise limit the size of the smallest feature which could be imaged using optical lithography.

Optical Lithography refers generally to the technology which enables etching patterns on a substrate through use of photographic development of images which have been attached onto the surface of the substrate using a mask. Generally, the process involves directing ultraviolet light through a photomask to expose a light-sensitive film previously deposited on the substrate. If the light-sensitive film is a so-called positive resist and the resist is located beneath a clear area in the photomask, the resist undergoes a physical and chemical change that renders it soluble in a development solution. This process results in the transfer of an image from the photomask to the resist film. Finally, application of an acid to the surface will transfer the resist image into the surface of the substrate.

There are several known types of photomasks for use in lithography which employ phase shifting. The underlying concept of a phase shift mask is to introduce canceling interference of impinging light at portions of an image where diffraction effects have deteriorated the resolution of the image. This is accomplished by providing a mask with appropriately placed and appropriately selected thicknesses of optically transmissive materials so that the ultraviolet light waves which pass through the mask and then image on the target exhibit constructive phase addition at areas in which high intensity for imaging is desirable and destructive phase subtraction where low intensity is desired. Constructive and destructive phase is explained by considering light as a wave motion so that the effect of a number of wave trains arriving at a point depends on the phase as well as on the amplitude of each of the arriving

waves. If light from the same point source starts in phase and travels different paths through different materials to come together at a point, if the waves arrive in phase, they will reinforce each other, i.e., constructive interference. If light from more than one source arrives at the same point, if the various source emissions are coherent, i.e., same polarization, frequency and phase, then their waves can also combine constructively or destructively at the image. Accordingly, for phase shift masks to be effective, it is required that the light source emits light which is at least partially coherent.

A most significant application of phase shift masks in optical lithography is in the formation of electrical circuits on semiconductor materials in the manufacturing of integrated circuits such as semiconductor memory devices, microprocessors and other circuits. Other applications include the manufacture of compact discs and other laser readable memory devices. In the manufacture of integrated circuits, the apparatus most frequently employed to cooperate with the phase shift mask to image the phase shift mask onto the semiconductor substrate is called an optical stepper. The optical stepper positions and holds a wafer and photomasks provide the partially coherent ultraviolet light to image the various photomasks onto the wafer. Generally, the optical system, including the mask, is stationary and an image of a device is formed on a substrate positioned at the focal plane. Normally, the optical stepper is capable of moving the substrate horizontally, i.e., in steps, and permits the same optical exposure imaging process for the adjoining devices. The most common commercial steppers are called "I-line Steppers" where "I" designates that the wavelength of the ultraviolet source lamp being used, i.e., λ =365nm. A more advanced stepper employs a deep-uv source, where λ ≈250nm.

<u>Prior Art Attenuated Phase Shift Masks and Their Problems</u>

The underlying principals of the attenuated phase shift mask (APSM) are understood by reference to FIG. 1. A quartz blank 1 is illustrated having a layer thereon of an intensity absorbing and phase shifting material 2 which is shown having a pattern. Assume that the pattern is intended to cooperate with a coating of positive resist on an underlying substrate (not shown). In the pattern regions 4 of the mask where the absorber is not present, the UV light rays 3 which pass through the mask have a nominal electric field of +1 at zero phase angle as seen at 5 in FIG. 1B. The portion of light in region 6 which has exited the absorber/phase shifter material 2 has an amplitude of 0.3 at 180° phase angle. This exiting light pattern exhibits an E-field pattern at the wafer as seen in FIG. 1C. The E-field pattern squared is proportional to the intensity. Since the resist materials coated on any substrate being patterned,

as seen in FIG. 1D, are sensitive to the intensity of the impinging light, if the intensity of the light in the region 6 is below the activation threshold of the resist, the pattern depicted by the pattern on the quartz wafer 1 will be accurately represented for most purposes. However, as recognized in the prior art with reference to FIG. 2, when the pattern in the mask is dense, i.e., such as pitch 0.7 ~ 0.9 microns with a hole of dimension D such as 0.35 to 0.45 microns, a constructive interference effect occurs which can cause the printing of a false image. This difficulty is studied in the article by IK-Boum Hur et al., entitled "Effect of pattern density for contact windows in an attenuated phase shift mask," SPIE, v.2440, pp. 278-289. This interference is called a sidelobe effect which prints an erroneous image at 30, FIG. 3. As seen in FIG. 4, in such arrays, the sidelobe intensity can exceed the printing threshold.

The intensity pattern of FIG. 1D is produced if the wafer intensity resulting from the mask of FIG. 2 is viewed along B-B' of FIG. 2. However, if the wafer intensity resulting from the phase shift mask of FIG. 2 is viewed along line A-A', the intensity pattern as depicted in FIG. 4 is seen to occur. As seen in FIG. 4, the intensity of the sidelobe is 50% of the peak. FIG. 3 illustrates the intensity gradient along A-A' in another way and shows how the sidelobe will cause another circle, i.e., the false image, to be printed between the four openings in the region 30. The E-field intensity gradient appears as symmetrical circles in the regions FIG. 3, 31-34 on the wafers, even though the mask has square contact openings D, FIG. 2.

The IK-Boum Hur article cited above also discloses a compensation approach to eliminate this cited sidelobe printing problem. The IK-Boum compensation approach is depicted in FIG. 5. A small additional zero phase opening 50 in the absorber layer is centrally located between each four zero phase openings in a regular array of zero phase openings. With reference to FIG. 6, if this centrally located zero phase opening 50 provides sufficient zero phase light at the central location at the wafer to cancel the 180 degree phase light arising from the constructive addition of light from the surrounding operations, then the central sidelobe is canceled out by destructive interference. This result is depicted in the graph of FIG. 6 which shows the light intensity along the diagonal A-A' of FIG. 5.

However, there are several serious difficulties in implementing the solution to the sidelobe problem as shown in FIG. 5. The area of the central zero phase opening must be small compared to the area of the surrounding openings and must also provide precisely the amplitude necessary to reduce the central 180 degree sidelobe to nearly a null. If the opening is too large, it will provide too much zero phase light which would result in printing the central opening.

Accordingly, as we reduce the critical dimensions of the overall array, the size of this central aperture must become sub-resolution and this becomes the limitation to further reductions in the critical dimensions of the array.

APSM are more fully described in a paper by B. J. Lin, "The Attenuated Phase Shift Mask," Solid State Technology, January 1992, pp. 43-47, which is incorporated herein by reference.

Summary of yhe Invention

It is the object of this invention to provide an APSM which avoids sidelobe printing.

It is a further object of this invention to provide an APSM which avoids the false sidelobe printing in a dense array where the smallest array critical dimension is not determined by a centrally located sub-resolution zero phase opening.

The method of making and the structure of this improved attenuated phase shift mask provides on a wafer significantly reduced critical dimension structures without sidelobe printing. This invention employs in a APSM an opaque structure in regions where sidelobes would constructively add, such as at the center region of an array of contacts and at the intersection of long lines. In the array situation, the opaque structure is approximately the same size as the contact zero phase openings. Accordingly, the size of the central sidelobe structure in my invention is not a process-limiting, sub-resolution feature which results in destructive interference but is instead an opaque structure blocking the sidelobe light from reaching the wafer thereby avoiding the sidelobe printing problem.

Brief Description of the Drawings

FIG. 1 is a cross section of a prior art attenuated phase shift mask (APSM) and its associated E-field and intensity graph.

FIG. 2 is a plan view of a portion of an APSM having a dense pattern.

FIG. 3 is a top view of an E-field intensity gradient at a wafer surface produced using the APSM of FIG. 2 showing an undesired sidelobe.

FIG. 4 is an intensity graph as a function of distance along the line A-A' of FIG. 3 illustrating the normalized intensity of the sidelobe.

FIG. 5 is a prior art APSM having a small central opening to provide out-of-phase light to cancel a central sidelobe.

FIG. 6 is an intensity graph of the prior art APSM of FIG. 5.

FIG. 7 is the top view of the mask blank after the first step to open a single contact opening down to the quartz substrate.

FIG. 8 is the top view of the mask blank after the second step of opening a modified crossing pattern down through the opaque layer to expose the attenuation layer.

FIG. 9 is a top view of a portion of a dense APSM array of an embodiment of this invention having an opaque portion centrally located between zero degree opening portions.

FIG. 10A is the side view of the preferred structure along line A-A' of FIG. 9.

FIG. 10B is the E-field at the mask corresponding to the structure of FIG. 10A.

FIG. 10C is the intensity at the wafer corresponding to the structure of FIG. 10A.

FIG. 11A is a top view of a mask having a large isolated structure and a dense array structure where sidelobe printing results.

FIG. 11B is an intensity plot at the wafer for the mask of FIG. 11A.

FIG. 12 is a top view of a APSM with an opaque region to avoid sidelobe printing in connection with large isolated structures such as FIG. 11A and 11B according to the invention.

FIG. 13 is top view of APSM with large isolated structure alternative according to the invention.

FIG. 14A is top view of mask having both a large isolated structure and a dense array without sidelobe printing.

FIG. 14B is an intensity plot at the wafer for the mask of FIG. 14A.

Detailed Description of the Invention

With reference to FIG. 10A through 10C, I disclose a patterned reticle, i.e., a photomask, made of a transparent substrate having at least two layers thereon. The blank is a transparent substrate 100 which provides the mechanical rigidity to the reticle. The substrate has a layer 102 of absorber/phase shifter material adhered thereto and a layer 101 of opaque material is adhered to the absorber 101 The transparent blank 100 is preferably made from quartz of approximately 6.35mm thick. The absorber/phase shifter is preferably made from a known compound of Molybdenum Silicon Oxynitride (MoSiON). For use with an I-line source lamp, the thickness is on the order of 1000Å to achieve π (180 degree) phase shift and 90% absorption and the opaque layer is preferably chrome of 800Å±200Å thickness. This layered blank has been made into a mask which will reliably form a dense array on a wafer of contact openings having dimensions on the order of 0.45 to 0.30 microns on a 1.0 micron pitch (or more dense). Other absorbers and opaque materials are also known.

To pattern the mask using a sequentially layered blank 100 having layers 102 and 101 thereon, I first coat the layered blank with a resist on one face and perform an e-beam write to expose the resist with the pattern for the zero degree phase portions which will correspond to the contacts for a positive resist. Next, the blank is developed, the resist removed and the reticle is etched through the two layers 101 and 102 until the surfaces 103 of the quartz are exposed. FIG. 7 illustrates the top view after completion of the first write step for an isolated zero degree phase opening. Next, the blank is recoated with resist and a second e-beam write step is carried out to form a pattern for removing some of the opaque material, i.e., the chrome 101, in order to expose a portion of the 180 degree phase shifter absorber layer contiguous to the zero degree phase openings. After this write step, the blank is developed again and etched, and the reticle is now complete. FIG. 8 is illustrative of the top view of an isolated opening showing the preferred pattern for a dense array. FIG. 9 is illustrative of a top view of a dense array of six openings according to the invention.

With reference to FIG. 8, it can be seen that each zero degree phase opening 103 is completely surrounded by at least a small region 104 of exposed 180 degree absorber/phase shifter. At the corners of the zero degree openings along the diagonal A-A', it can be seen that the pattern of the exposed 180 degree phase shifter material has a corner enlargement so that zero degree openings have an 180 degree exposed region adjacent to every point on the periphery of the zero degree openings. However, the enlarged corner is minimized so that the central region 105, where the opaque layer is retained, is as large as possible. For example, the opaque central region 105 is approximately the same size in area as the contact opening. By retaining the opaque region 105 as large as possible, the detrimental sidelobe which forms in this region in the prior art is avoided and no sub-resolution size structures are employed. FIGS. 10B and 10C illustrate the mask E-field and the light intensity at the wafer imaging surface correlated to the features of the mask of FIG. 10A. It is of note that the intensity profile at the wafer (FIG. 10C) is essentially of the same form as is available from a completely different type of phase shift mask known as a RIM PSM, but my invention avoids the sub-resolution features required of a RIM PSM design.

The absorber/phase shifter layer 102 is described herein as a single layer but can be a multi-layer. It can be easier to employ a multi-layer of different materials to obtain both the desired attenuation and the 180 degree phase shift. A single material may not be able to provide both desired parameters simultaneously.

I have performed an aerial image simulation to compare the exposure and defocus process latitudes for a protected 9% attenuated phase shift mask of my invention to a standard 9% APSM over a range of numerical aperture values. (The standard 9% APSM used in the simulation did not include the central 0° phase aperture of the IK-Boum Hur et al., article). A 9% APSM passes 9% of the impinging UV field intensity through the absorber/phase shifter. Before calculating the process latitudes, the contact opening sizes were biased so that an aerial image at the wafer was 0.45 micron wide at a 0.3 intensity contour at best focus. This assumes printing will occur if the aerial image is above 0.3 intensity, normalized at 1.0 for open field transmission. Table I shows both the intensity peak at the center of the contact and the sidelobe intensity along the diagonal (the sidelobe is larger on the diagonal).

The exposure latitude (EL) parameter is defined as follows for the simulation:

$$EL = \frac{\text{dose range to print over } 0.450 \pm 0.045 \text{ microns}}{\text{dose to print at } 0.450 \text{ microns}} \times 100$$

The depth of focus (DF) is defined as:

DF= the amount of defocus at which the 0.405>print size>0.495 microns

TABLE I			
NA	Parameter	51 Element Illuminator	
		Standard 9% APSM	Protected 9% APSM
0.48	Contact size (μ)	0.52	0.54
0.48	Sidelobe/peak	0.22/0.82	0.09/0.78
0.54	Contact size (μ)	0.50	0.50
0.54	Sidelobe/peak	0.21/1.1	0.12/1.12
0.6	Contact size (μ)	0.48	0.48
0.6	Sidelobe/peak	0.21/1.36	0.16/1.32
0.48	EL (%)	45.10637	44.35149
0.48	DOF (μ)	1	0.85
0.54	EL (%)	61.3334	58.51527
0.54	DOF (μ)	above 1.0	0.9
0.6	EL (%)	76.19047	70.76926
0.6	DOF (μ)	above 1.0	0.85

As can be seen from Table I, the simulation indicates that for a 51-element illuminator array of an ASML 5500/100 stepper that the protected 9% attenuated phase shift array of my invention enjoys a substantial reduction in sidelobe/main peak ratio for all NA values while the EL and DOF remain essentially unchanged.

The area ratio $R = \frac{A_o}{A_A}$ or opaque area (A_0) to absorber area (A_A) over a large pattern can be varied substantially for the protected APSM of this invention and still obtain the sidelobe elimination benefit. For the preferred modified cross design of FIG. 9, $R = \frac{12}{17}$. For the same pattern with 51 zero degree phase openings $R \approx 1$. It is also apparent that the rectangular array

pattern of FIG. 9 is not essential and that the absorber pattern could be skewed with respect to the contact pattern without affecting the benefits of this concept.

As stated earlier, in the prior art, to reduce the sidelobe intensity below the printing threshold, it is necessary, in the λ =365nm stepper system, to use sub-critical feature size dimensions for the array center aperture in dense arrays in order to provide the proper amount of 180 degree light. In fact, in order to provide the same amount of sidelobe cancellation as is achieved with the opaque array center of this invention, it is necessary to provide array center clear openings having feature sizes less than 0.25μ. Clearly, to reliably obtain a 0.25μ spot is very difficult in the λ =365nm system.

For features other than small contact openings, such as long lines and crossing lines, constructive interference can also result in sidelobe printing at corners of such features and between long lines, as illustrated in FIG. 11B. For the mask pattern employing a 9% transmission phase shifting material and having the pattern configuration illustrated in FIG. 11A having a dense contact opening array 50 of the type illustrated in FIG. 5 as well as long lines 51 and intersections 52. We have found that serious sidelobe printing errors can occur along the long lines and especially at their intersections 52. FIG. 11B is a light intensity profile on the wafer produced with a mask of FIG. 11A. The 100% indication corresponds to the light intensity on the wafer seen to occur directly under the clear mask region in 53 having the long lines and the clear contact regions 54 in the dense array 50. Assuming that the printing threshold of the resist requires at least 30% of the clear region illumination intensity, it can be seen that for the dense array 50, the illumination intensity above the print threshold at the wafer is restricted to the contact openings 54. However, for the long line pattern configuration region 55, the situation is very different. At the corners near 52 and between the lines 51 in the region 52', it can be seen that 30% light intensity regions are developed which show that the resist in these areas will be exposed sufficiently to develop the resist so that it erodes to the substrate directly below the regions marked 30% on FIG. 11B as well as the regions marked 100%. There are also seen in FIG. 11B long regions at 10% which frequently also receive 30% and result in erroneous printing of long lines parallel to the intended pattern 53.

With the reticle blanks having the absorber and opaque layers of this invention, the large feature sidelobe printing is eliminated by providing an opaque region contiguously along the periphery of all mask large-feature corners, and contiguously bordering all mask long-line features with the opaque layer material. The simplest method to achieve this result is to start

with a blank reticle having an absorber and opaque layer on a substrate and allowing the opaque layer, i.e., chrome, to remain in place around all large features. From a process standpoint, this can be accomplished in the mask defining and manufacturing process without any manual intervention since the chrome will remain in place everywhere except where the absorber is exposed in the image of the feature. As explained earlier, in connection with the APSM solution for the dense array features, in this invention there is no requirement to form any sub-resolution features to eliminate and avoid sidelobe printing for either arrays of small features or for large features. In theory, my invention is to place an opaque region on the APSM mask in every region of the mask which corresponds to a location where a sidelobe of sufficient intensity to print appears on the image. In practice, this result is accomplished by starting the APSM mask manufacturing process with a transparent reticle (blank) having absorber and opaque layers over their entire surface, and then leaving the opaque layer in place wherever the absorber layer is not intentionally exposed. This is accomplished using a first e-beam step to define, develop and expose 0° regions, and a second e-beam step to define, develop and expose 180° regions. The remaining regions are covered by opaque material.

As seen in FIG. 12, for a large structure, in corner regions 100-104, sidelobe printing is a problem. To compensate, it is adequate to remove the absorber and opaque layers to reveal the 0° phase only corresponding to the image of the feature, in this case a large "L" shape. If the feature is to be near other features, it is adequate to rim the 0° phase with an opaque contiguous region 105 of approximately the same width as the feature, as shown in FIG. 13.

For such large features, the improved resolution obtainable using phase shift mask techniques is not required to achieve good control of the critical dimension. However, since sidelobe printing can be a problem for larger features also, the benefits of this invention can improve imaging of both large features as well as dense arrays of contact openings at the critical dimension on the same circuit.

With reference to FIG. 14A, a mask is illustrated which is identical to the mask of FIG. 11A except for the rim region 60 of opaque material, which is a border around the long line pattern 53. FIB. 14B illustrates the light intensity wafer illumination gradient for the mask of FIG. 14A. Note that outside of the large intended pattern region 55' as well as within the dense contact region 50, that the light intensity is at the 30% resist threshold point or lower except in the desired pattern erosion regions.

It is not my intention that this invention is to be restricted to the embodiments disclosed herein and accordingly the scope and extent of the invention should be controlled by the claims.

With this in view,

I CLAIM:

1. In an attenuated phase shift mask (APSM) for producing a dense array of like shapes in a lithography process, said APSM having a transparent substrate, a thin first layer, said first layer being of absorbing and phase shifting material adhering to one surface of said transparent substrate,

THE IMPROVEMENT COMPRISING:

a thin second layer, said thin second layer being of opaque material adhering to said thin first layer of absorbing and phase shifting material;

said dense array of like shapes having on the surface of said transparent substrate a corresponding dense array of a plurality of 0° phase portions, said 0° phase shift portions being formed by regions of said one surface of said transparent substrate being devoid of both said first and said second layer;

a 180° phase portion, said 180° phase portion being comprised of said first layer, said 180° phase portion being contiguous to every point of the periphery of said zero degree phase portions of said corresponding dense array, said 180° phase portion being devoid of said second layer; and

said second layer having portions overlying substantially all of the area of said first layer located in the region centrally located between any adjacent four said zero degree phase shift portions.

2. The APSM of claim 1 wherein said corresponding dense array of a plurality of zero degree phase shift portions comprises an array of square-shaped openings through said first and second layers.

3. The APSM of claim 2 wherein each character of said array corresponding to said 180° phase shifting portion has a cross shape with said zero degree phase portions being located in the central region of each said cross shape.

4. THE APSM of claim 2 wherein each said 180° phase shifting portion cross shape has an enlarged region adjacent to the corners of said zero phase portions.

5. The APSM of claim 4 where said enlarged region has a shape which corresponds to the shape of said most adjacent portion of said zero phase regions.

6. The APSM of claim 1 wherein said transparent substrate comprises quartz.

7. The APSM of claim 1 wherein said first layer comprises a compound of Molybdenum Silicon Oxynitride.

8. The APSM of claim 7 wherein said second layer comprises chromium.

9. The APSM of claim 8 wherein the first layer is 600Å to 1000Å thick and the second layer is on the order of 1000Å thick and the second layer is on the order of 1000Å thick.

10. The APSM of claim 2 wherein the ratio of the aerial image forming area of said first layer to the aerial image blocking area of said second layer is on the order of 1.

11. A patterned phase shift mask reticle for producing a dense pattern having two broad area sides comprising:

a transparent substrate, said substrate having a first and second surface;

a first layer, said first layer comprising an absorber and phase shifter material, said first layer being directly in contact and adhering to said first surface of said substrate;

a second layer, said second layer being opaque to light and positioned to cooperate with said first layer and said substrate such that wherever said second layer is in place, no light coming from behind said second layer and being directed toward said substrate is able to be transmitted through said second layer to the opposite side of said reticle;

said first and second layers being patterned so that 0° phase shifted light transmits through said transparent substrate and not through said first or second layer and so that phase shifted light transmits through said transparent substrate and through said first layer and not through said second layer;

wherein said pattern comprises a plurality of 0° phase shift portions, each said 0° phase shift portion having a phase shifted portion surrounding and contiguous thereto;

said second layer further being positioned to block any light from transmitting through said reticle in the regions centrally located between any four adjacent said 0° phase shift portions.

12. The patterned reticle of claim 11 wherein a plurality of said 0° phase shift portions are squares of periphery 4d and arranged in an array having a pitch p, where d is on the order of 0.50 microns or less and p is on the order of 0.70 microns or less.

13. The reticle of claim 12 where the aerial image forming area of said 0° phase shift portions are approximately one-half the aerial image forming area of said phase shifted portion.

14. The reticle of claim 13 where the aerial image forming of said 0° phase portion is approximately equal to the aerial image forming portion of said second layer opaque region.

15. The reticle of claim 13 where said phase shifted portions are enlarged in the regions near the corners of said 0° phase portions.

16. The method of fabricating an attenuated phase-shift mask for cooperating with a light source of wavelength λ for producing an integrated circuit, comprising:

(a) providing a transparent substrate having a coating layer of approximately $\lambda/2$ thickness phase shifter material directly thereon and a coating layer of opaque material adhered directly to said $\lambda/2$ phase shift layers, said coated substrate being a blank;

(b) coating said blank with a radiation responsive resist material;

(c) exposing said resist to a first radiation dose to pattern said resist for zero phase angle regions in a desired mask pattern and developing and removing the soluble portion of said resist;

(d) removing said $\lambda/2$ layer and said opaque layer in said areas of said blank corresponding to said first radiation dose where said soluble portion of said resist has been removed;

(e) recoating said blank with a second layer of resist;

(f) exposing said resist to a second radiation dose to pattern said resist for π phase angle regions in a desired mask pattern and developing and removing the soluble portion of said resist;

(g) removing said opaque layer in said areas of said blank corresponding to said second radiation dose where said soluble portion of said second layer of resist had been removed;

(h) removing all remaining resist; and

(i) wherein said step of exposing said resist to a second radiation dose for π phase angle regions to form a π phase shift region devoid of said opaque material is applied to areas of the blank forming dense arrays of like shaped features where the pitch between adjacent said features of said dense array is approximately 2λ.

17. The method of claim 16 wherein said step of exposing said resist to a second radiation dose to form a π phase shift region devoid of said opaque material is caused to expose said resist in the region contiguous to and completely surrounding all zero degree phase angle regions patterned in step (c) herein above.

18. The method of claim 16 wherein said $\lambda/2$ phase shifter layer is MoSiON.

19. The method of claim 17 wherein said opaque layer is chrome.

20. The method of claim 16 wherein said resist is a positive resist material.

21. The method of claim 16 wherein in step (f) said second radiation exposure is restricted from the zone along the edge of large features so that the opaque material remains contiguous to zero phase angle features regions other than dense contact array openings.

22. The method of claim 21 wherein the large feature is a long line of width d and said restricted zone along the edge of said long line is of a width at least equal to d.

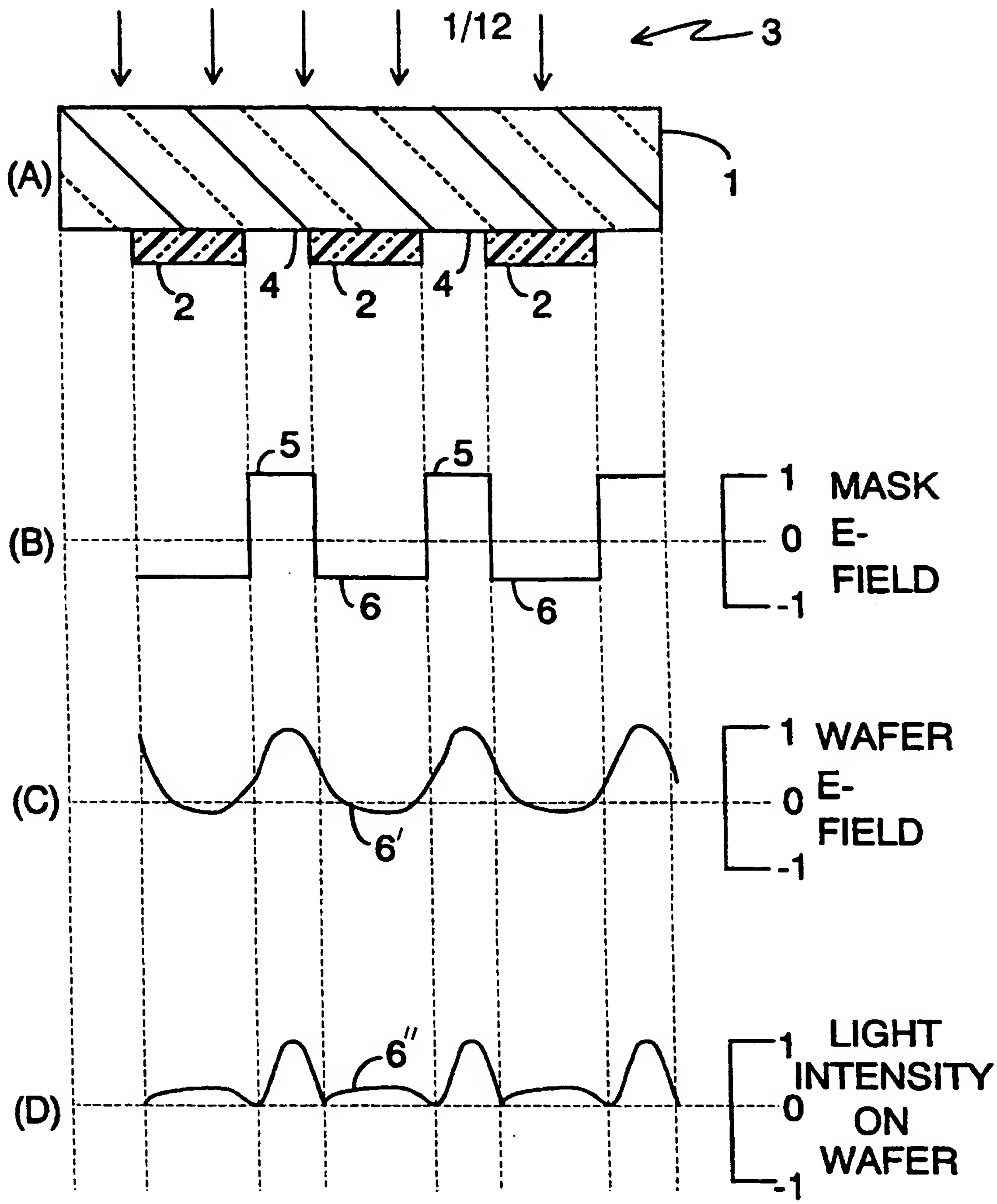


FIG. 1
PRIOR ART

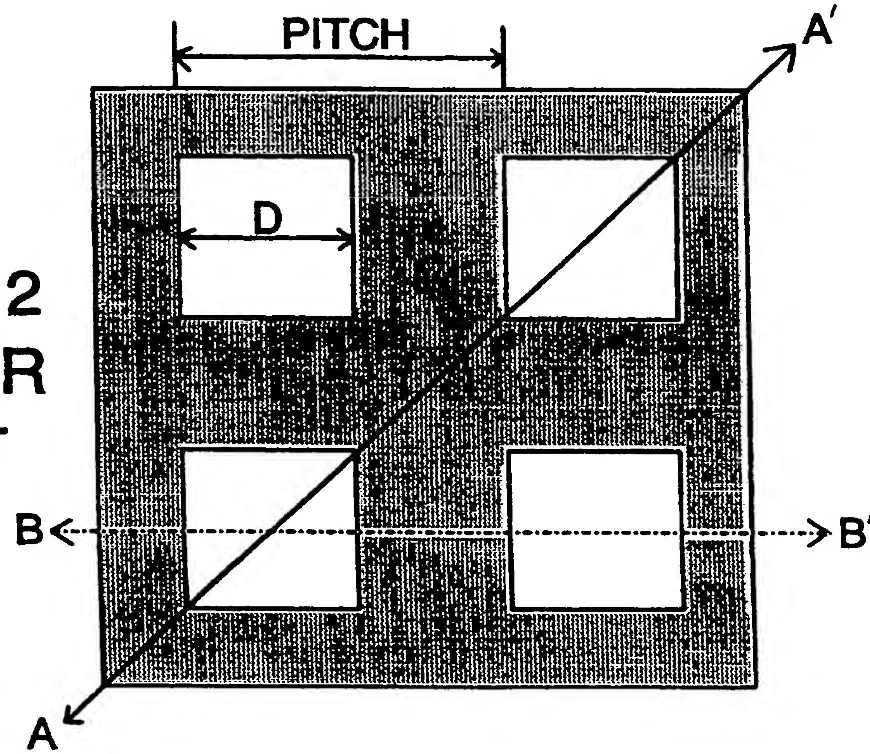


FIG. 2
PRIOR
ART

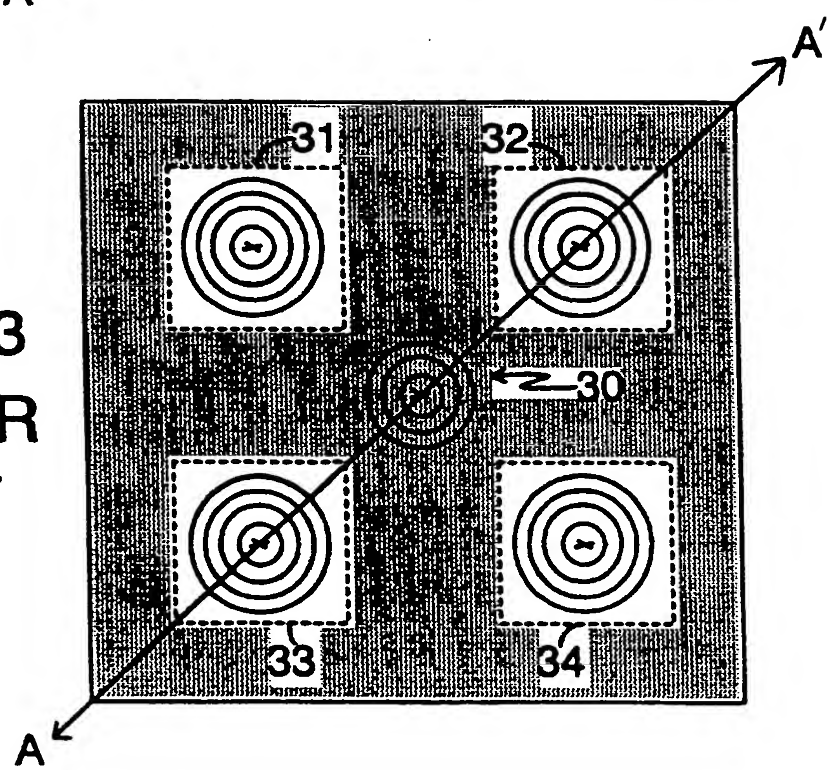


FIG. 3
PRIOR
ART

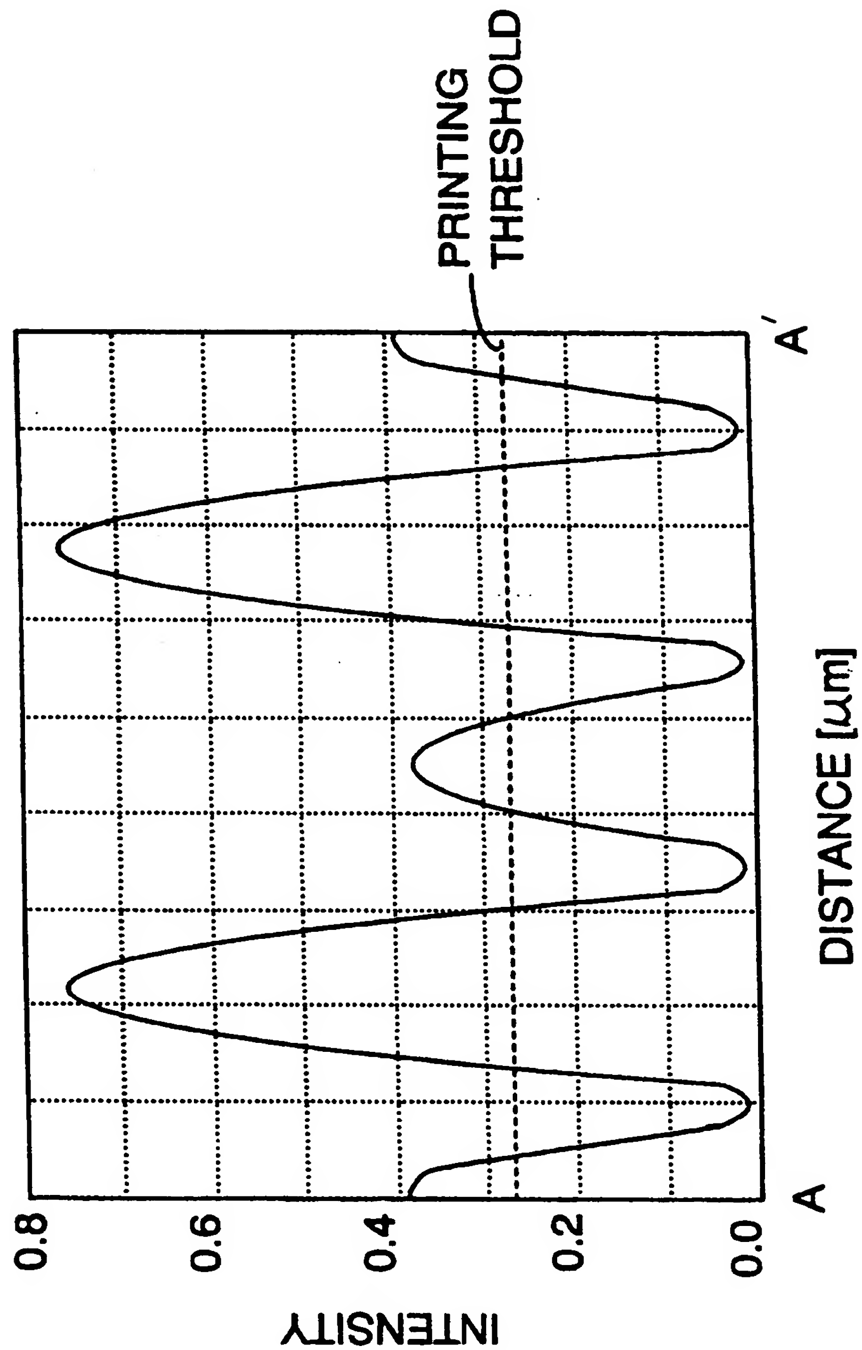


FIG. 4
PRIOR ART

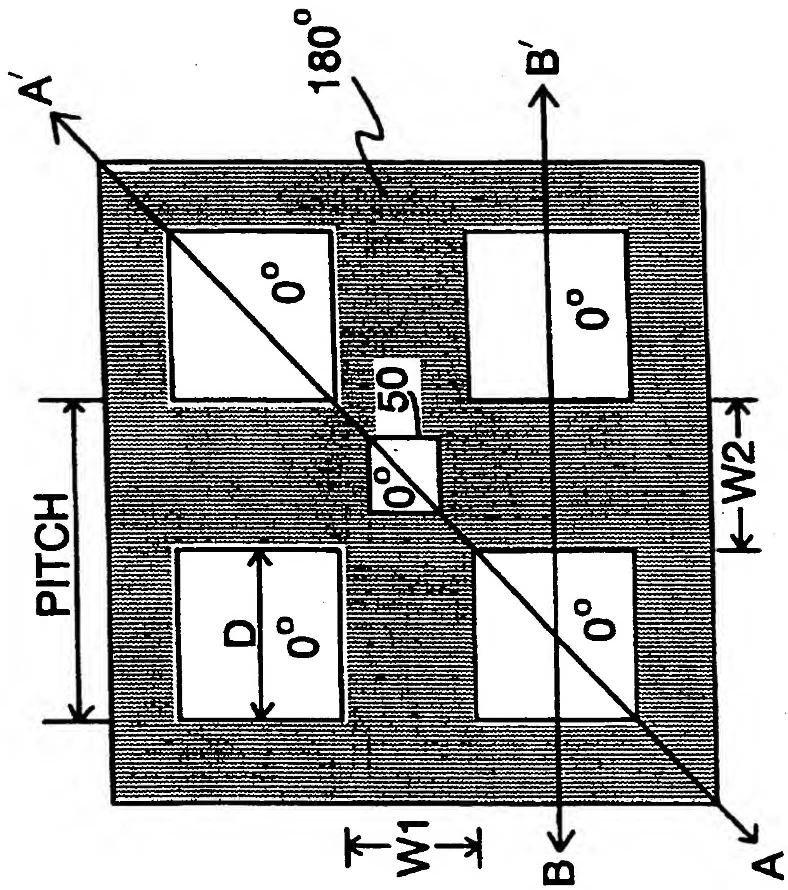


FIG. 5
PRIOR
ART

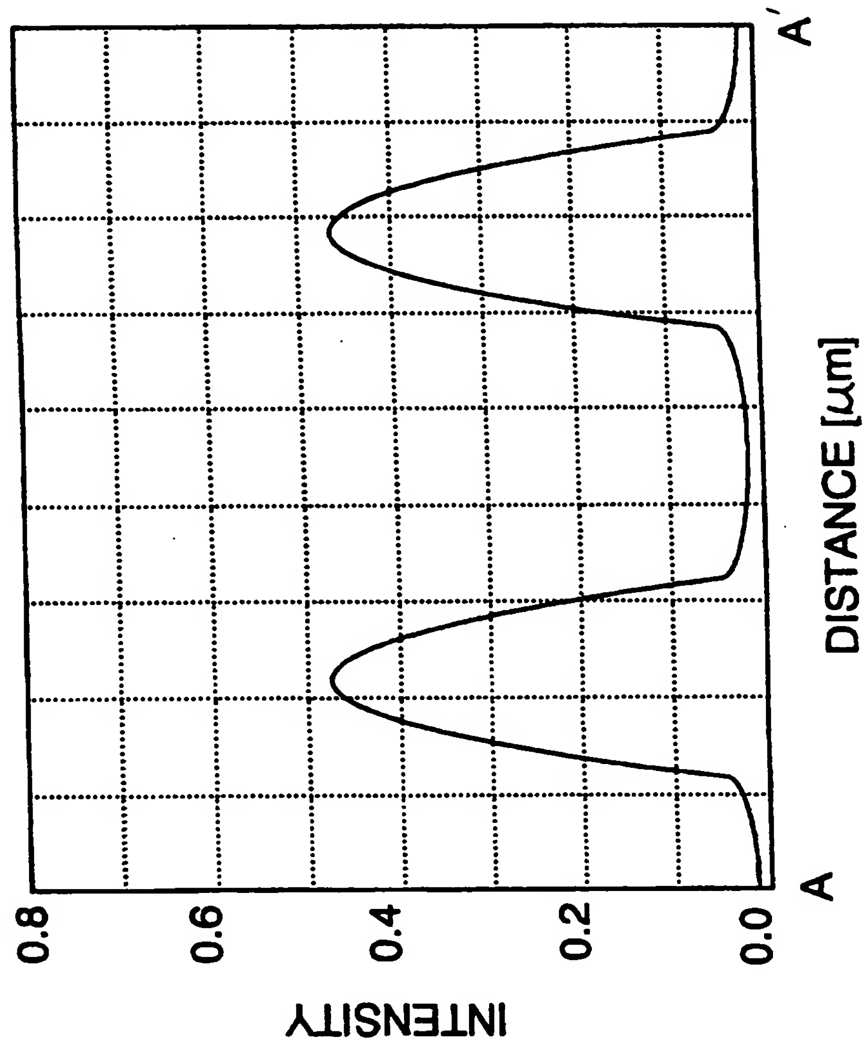


FIG. 6
PRIOR ART

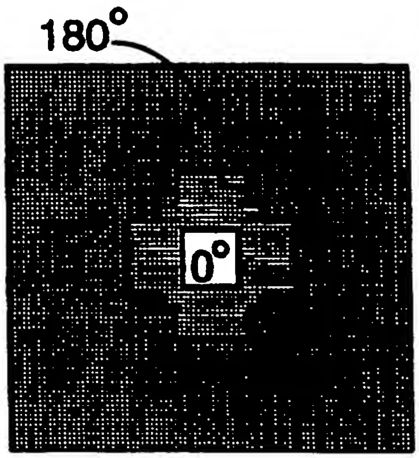


FIG. 8

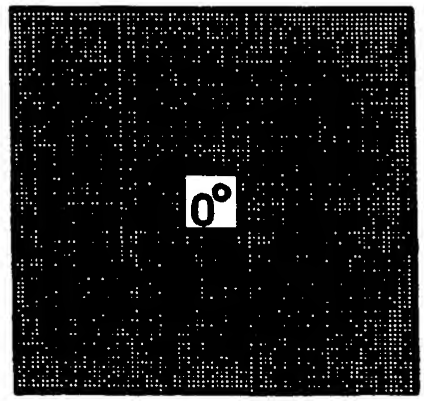


FIG. 7

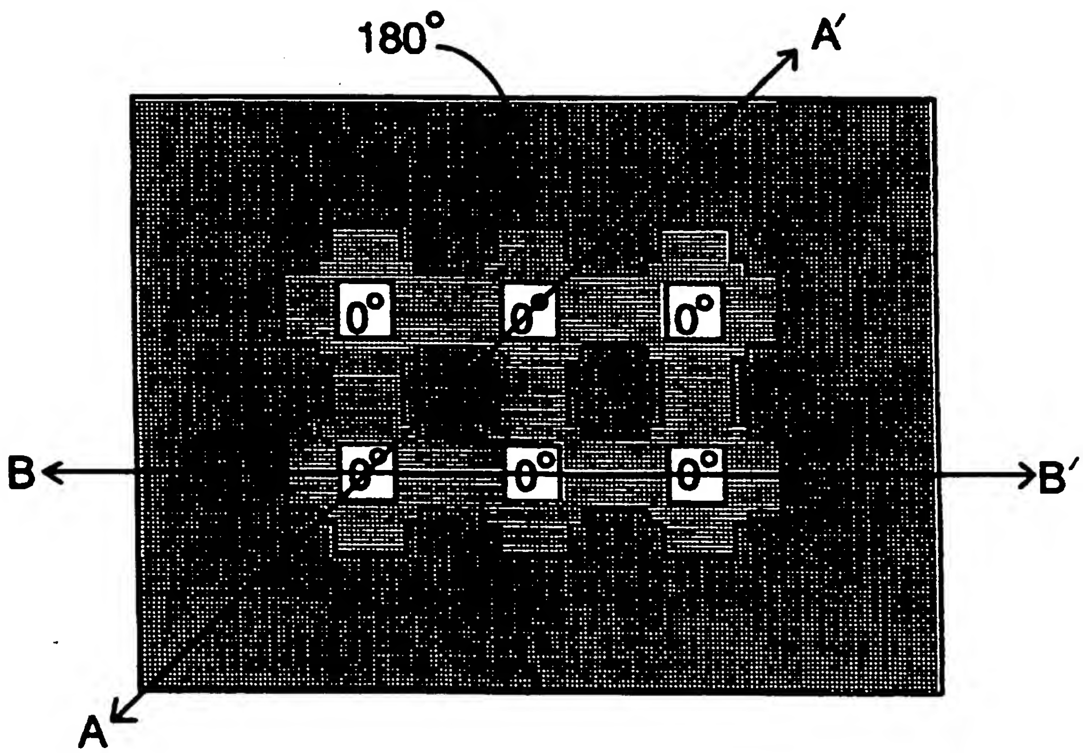


FIG. 9

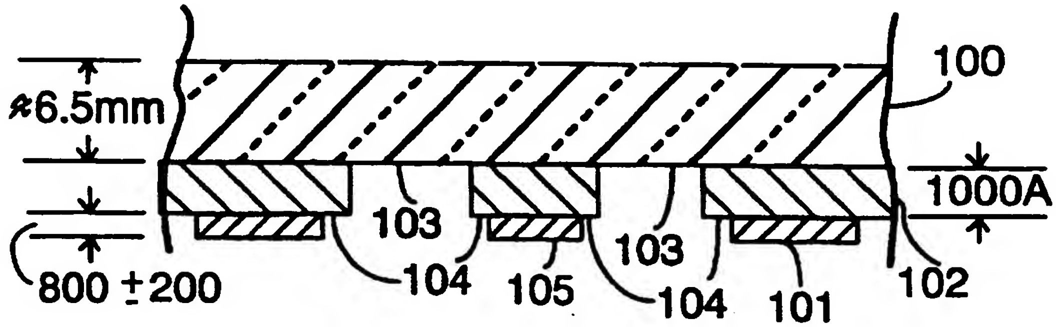


FIG. 10A

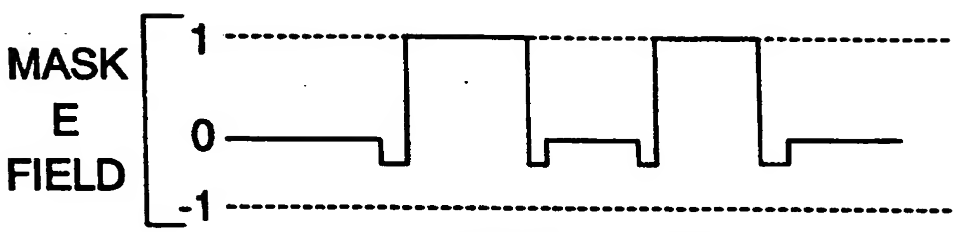


FIG. 10B

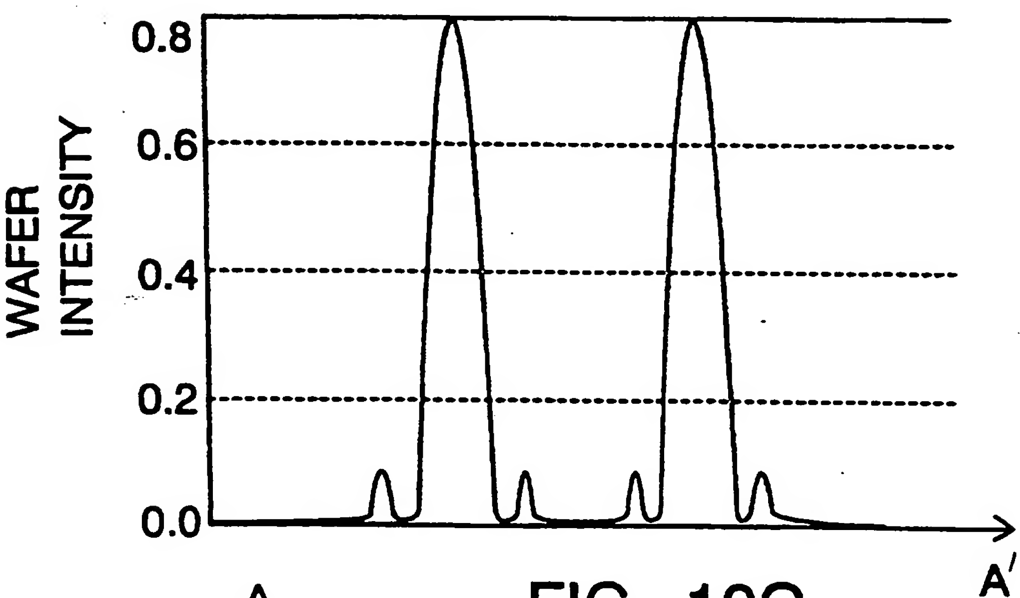
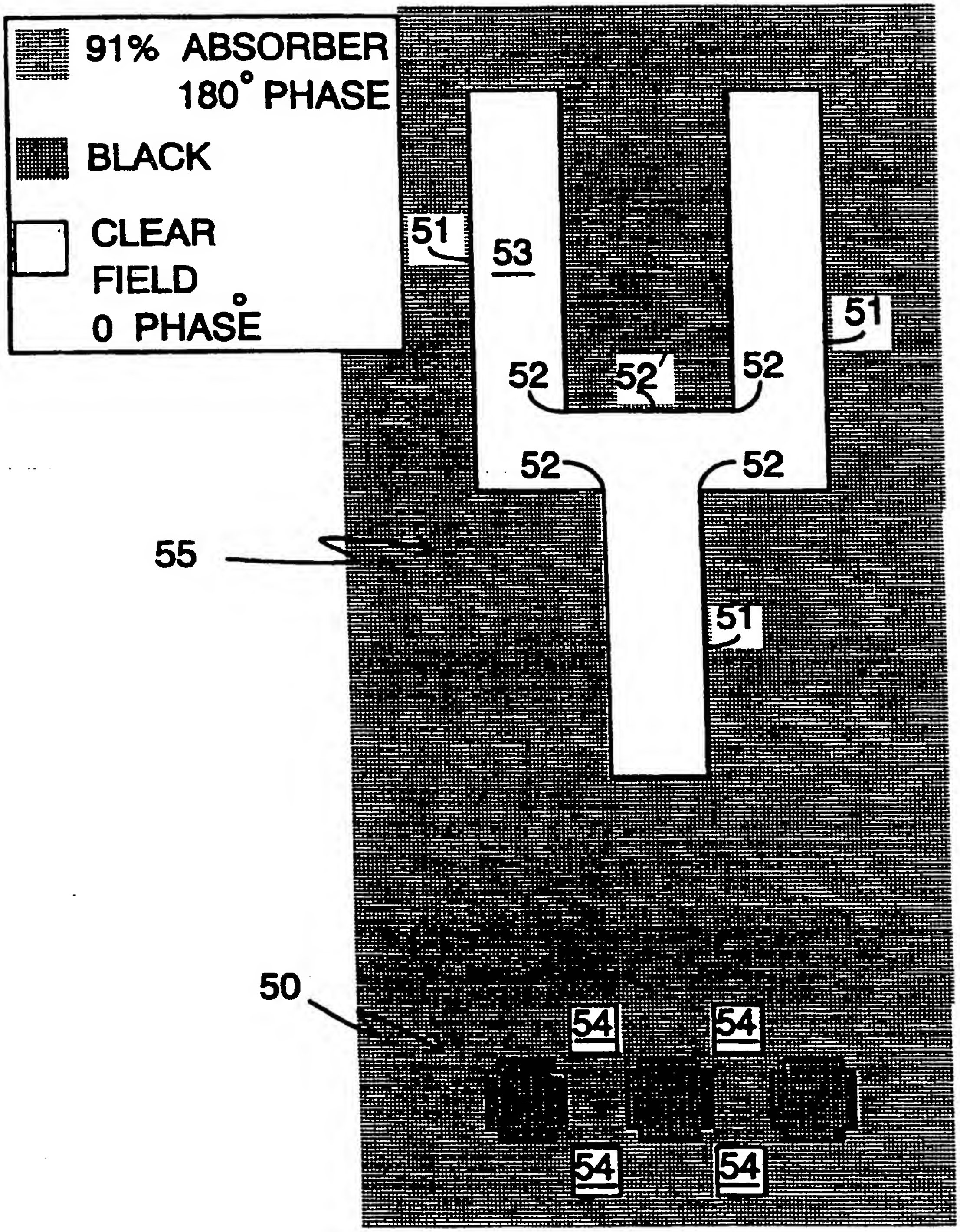


FIG. 10C


91% ABSORBER
180° PHASE
BLACK
CLEAR
FIELD
0° PHASE
51
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52'
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52
52
55
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50
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54
54
54

FIG. 11A

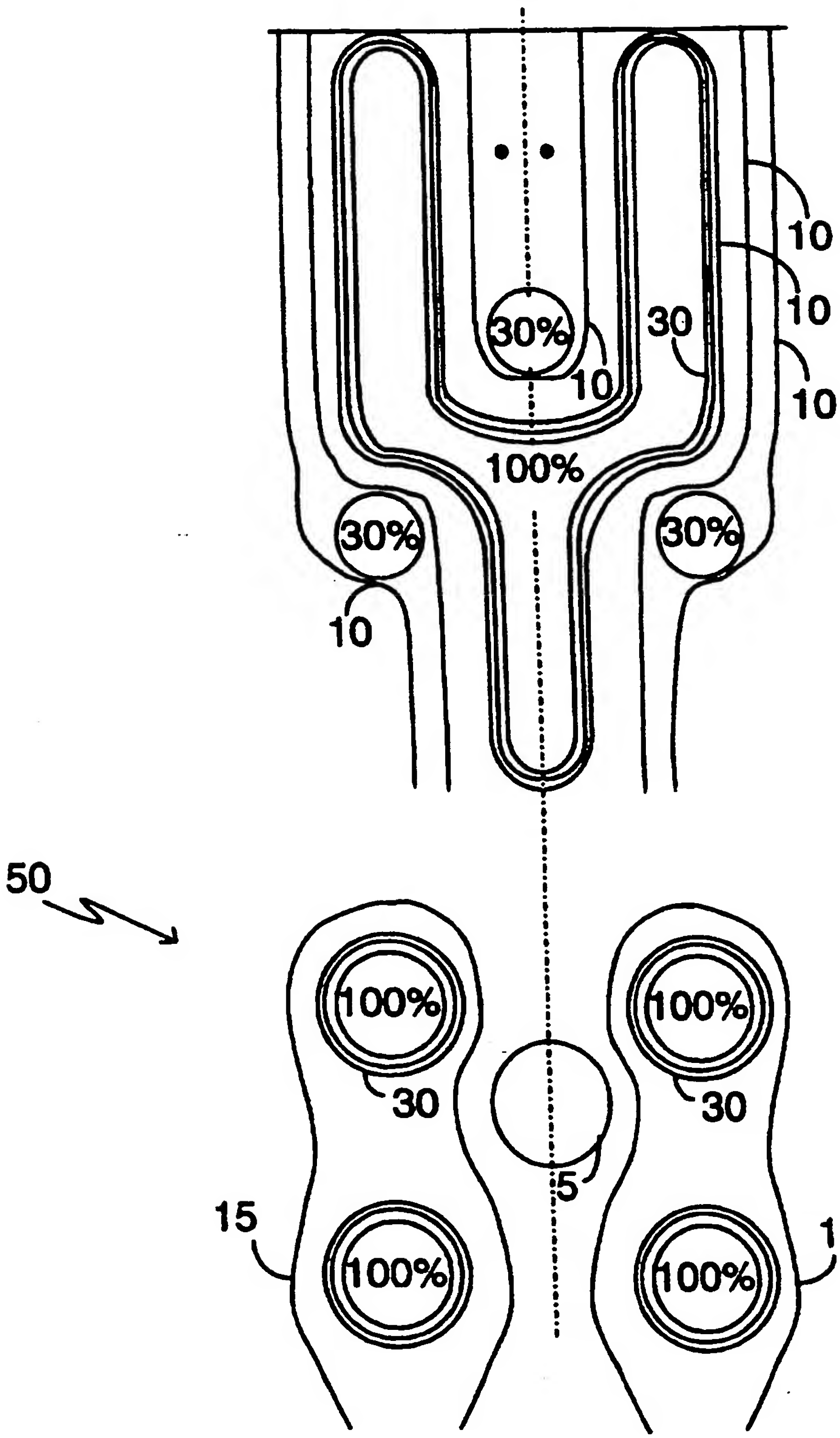


FIG. 11B

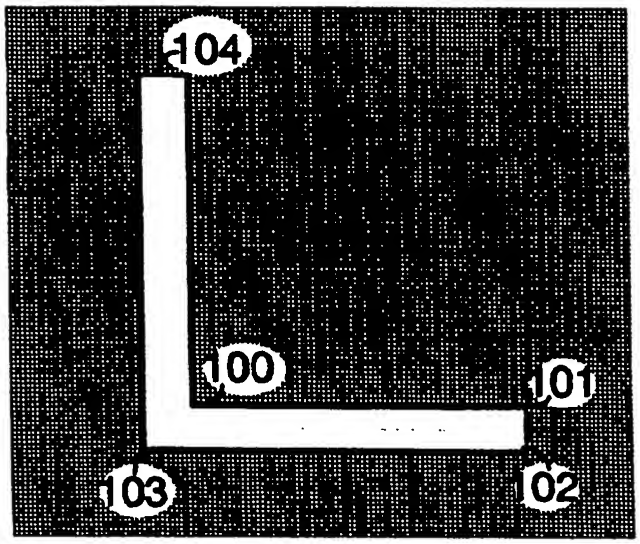


FIG. 12

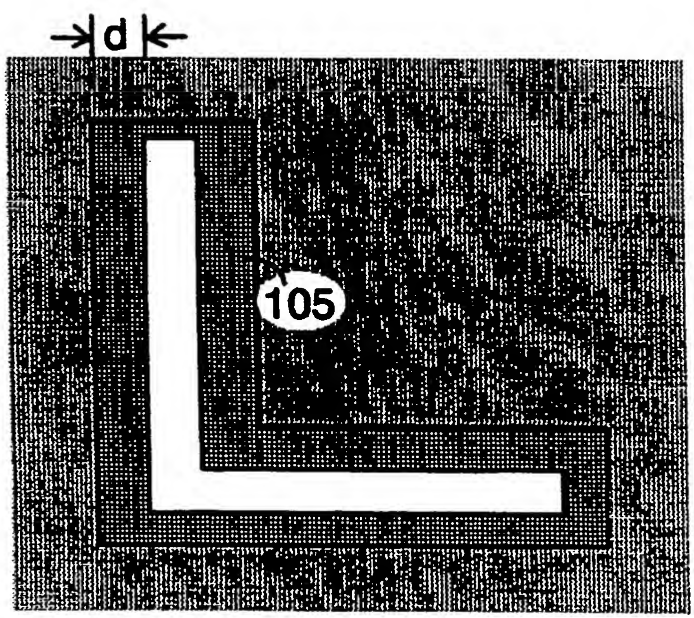
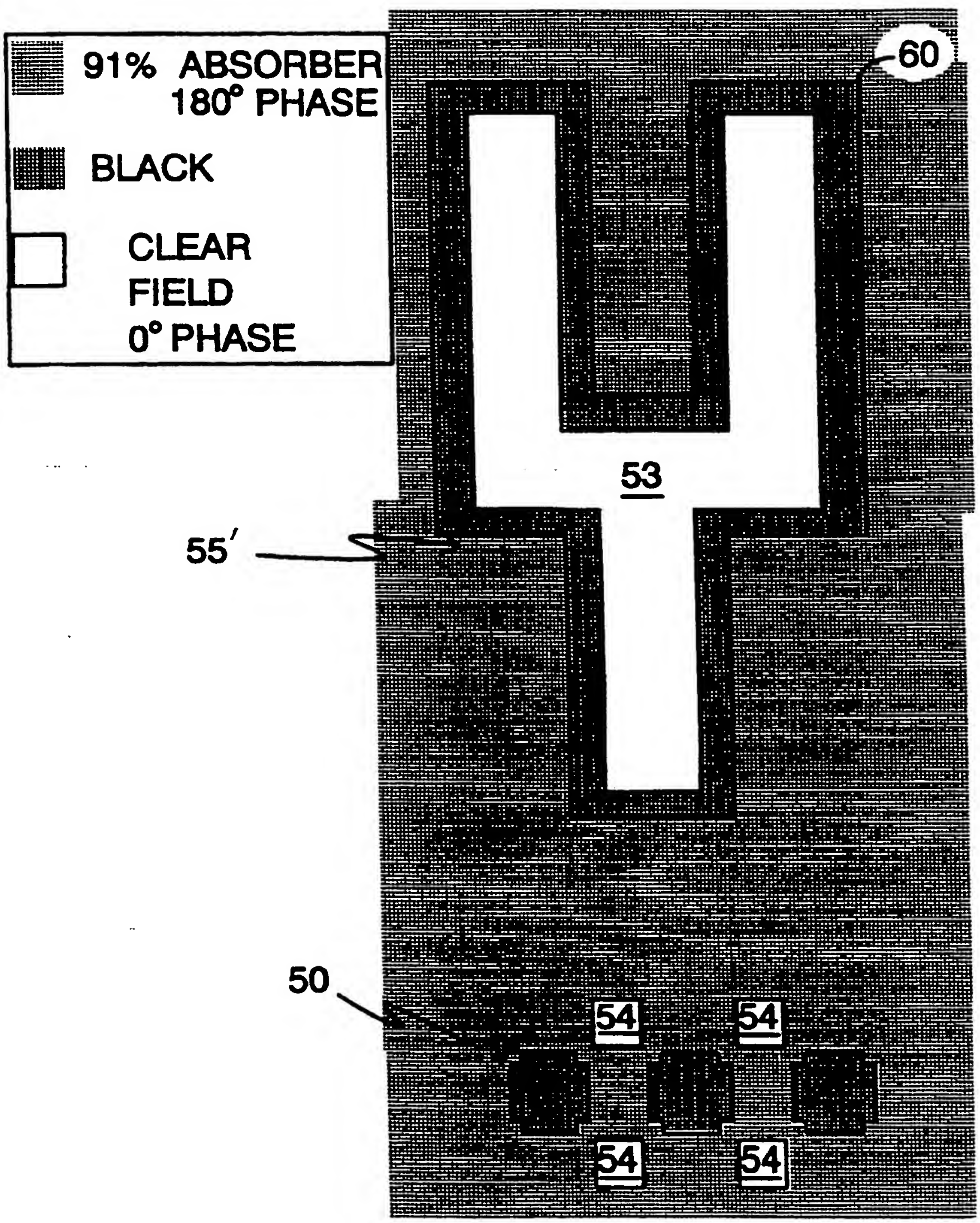


FIG. 13



91% ABSORBER
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FIG. 14A

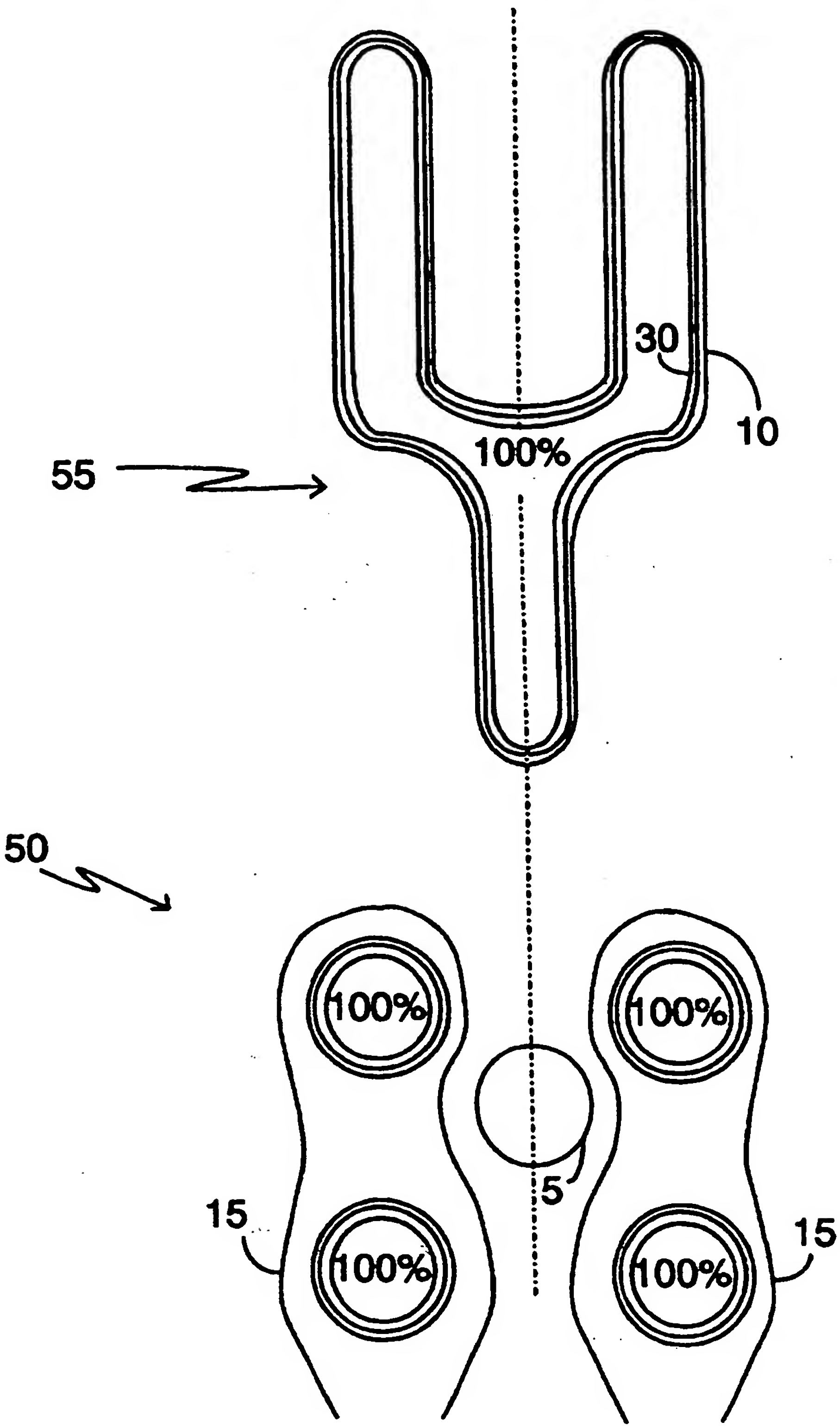

FIG. 14B